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Elephant GPS Tracking Collars: Is There a Best?

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Abstract. GPS tracking collars are an extremely useful tool in research, conservation and management of endangered Asian elephants. We provide an assessment of six GPS elephant tracking collar models from four manufacturers, based on field experience of collaring 51 elephants in Sri Lanka. Variations were observed among collars in the configuration and materials used, ability to obtain and transmit GPS locations, longevity, reliability and cost. There was no clear 'winner', the best choice depending on the type of study, area of use, financial and logistic constraints, importance of data quality vs. quantity and desired lifetime of the collar.

Introduction

Asian elephants (*Elephas maximus*) are 'forest-animals' mostly occupying poor visibility habitats. They have large home ranges and can move long distances rapidly (Fernando *et al*. 2008, 2012). Due to ubiquitous conflict with people, most Asian elephants are behaviourally adapted to avoid humans (Fernando *et al*. 2008). Consequently, unlike African savannah elephants (*Loxodonta africana*), Asian elephants are difficult to study by direct observation. Over the last decade, human-elephant conflict has escalated across the range (e.g. Baskaran *et al*. 2011; Fernando & Pastorini 2011; Saaban *et al*. 2011). Thus, management interventions are becoming essential for conserving elephants and mitigating human-elephant conflict across Asia.

GPS collars are an invaluable tool to study elephant behaviour and obtain information for their management (Campos-Arceiz 2008; Fernando *et al*. 2010, 2012; Alfred *et al*. 2012; Pastorini *et al*. 2013). Being of comparatively recent origin, studies using elephant GPS collars have been faced with various issues related to functional and physical failure of collars (Pinter-Wollman 2009; A. Campos-Arceiz, N. Othman, pers. comm.). Currently a number of products are on offer from different manufacturers and knowledge of the relative strengths and weaknesses of different collars are an important consideration in starting a collaring program.

Since 2004 we have monitored 51 elephants using 41 GPS-satellite collars. Here we describe and compare performance of different models of elephant collars from several manufacturers and suggest features that would be of advantage in general and in terms of particular field situations and logistic considerations.

Methods

We used 41 collars from four manufacturers including two models each from two manufacturers hereafter referred to as "old" and "new" (Table 1).

Collaring was done as a collaborative project between the Department of Wildlife Conservation and the Centre for Conservation and Research to obtain baseline information and to increase effectiveness of elephant conservation and human-elephant conflict mitigation in Sri Lanka.

Six collared elephants died during the study period, five due to human-elephant conflict.

Table 1. Collars used in the study.

Manufacturer	Country	Year of use	N	Code
Telonics, Inc.	USA	2004	10	Telonics old
		2009	15	Telonics new
Vectronic Aerospace GmbH	Germany	2006	3	Vectronic old
		2009	8	Vectronic new
Followit Lindesberg AB	Sweden	2009	4	Followit
Africa Wildlife Tracking	South Africa	2009	1	AWT

One was a crop-raiding male who was shot by a farmer. Four were translocated males (see Fernando *et al*. 2012). One female got killed in a train accident. Five of the six collars were re-used. Most (N=31) collars were programmed to collect a GPS location every 4 hours. Four collars gathered locations 8-hourly (one old Telonics, two new Telonics and one AWT) and three collars (New Vectronic) hourly. One collar had a mixed schedule of 1 and 4 hours and three collars had 4 and 8 hourly schedules as they were reprogrammed on a different schedule when they were re-deployed.

Results

Collar design

All collars consisted of a GPS unit, VHF transmitter, batteries and satellite or GSM transmitter for data download, packaged into one integrated sealed unit. Sky orientation of the functional unit for satellite detection was achieved by a counterweight (Fig. 1). All collars had to be mounted on the elephant so that the functional unit and the counter weight were at opposite poles. To facilitate this, we numbered the corresponding sets of perforations on the sides of the collar on both inside and outside surfaces of the belting. The Africa Wildlife Tracking (AWT) collar came with numbered perforations. Collar size (length of belting) could be specified at ordering for all collars.

Old and new Telonics collars came in two segments with a 90 cm length of belting incorporating the functional unit and a longer belt incorporating the counter weight (Fig. 1A). The two pieces were bolted together with 5x5 cm metal plates and four 10 mm bolts at collaring. A series of perforations in the long belt segment allowed the collar size to be adjusted.

The old and new Vectronic, Follwit and AWT collars had the functional unit fixed to a single piece of belt to which the counter weight was attached directly with two or four 13 mm bolts and metal plates at collaring (Fig. 1B). Multiple perforations in the belting allowed changing the collar length in Vectronic and AWT collars. Followit collars had only a single set of perforations hence a fixed collar length. As it was not possible to estimate the required collar length with certainty before collaring, we made additional sets of perforations prior to collaring.

Belting

Old Vectronic collars used a rubberized canvas belting and the new Vectronic collars a similar belting that was thicker. Old Telonics collar belts were made of a woven nylon strap encased in a proprietary plastic sleeve and the new Telonics collars used belting composed of a wide nylon-mesh embedded in a plastic material. Followit collars used multi-layered canvas belting and AWT collars PVC belting.

In the old Telonics collars, sometimes the plastic sleeve became separated from the nylon strap after deployment and the collar filled with mud, substantially increasing the collar weight (Fig. 1C). The new Telonics belting overcame this problem, but made the top piece stiffer. As a result, it did not sit on top of the neck of females but slid to a side (Fig. 1D). This was not an issue with big males as the neck was very broad and the functional unit sat on top. Using the old belting for the top part and the new belting for the bottom solved the problem.

Collar function

All collars with the exception of AWT were shipped by the manufacturer in the deactivated mode and were switched on by removing an external magnet. Collars were activated a few days prior to collaring. Telonics collars used variations in the VHF 'beep' to indicate success of collar activation while Followit collars used a flashing LED. AWT collars were shipped in activated mode from the manufacturer.

Followit, Vectronic and Telonics collars came programmed by the manufacturer but were re-programmable by user prior to deployment by connecting to a computer. Vectronic collars were also re-programmable while deployed, via SMS communication with the collar. AWT collars were pre-programmed by the manufacturer and the schedule could not be changed anymore.

Telonics collars uploaded data through an Argos satellite system <http://www.noaasis.noaa.gov/ARGOS/>. The upload window had to be specified at the time of collar ordering based on the geographic location of deployment as a polar orbiting satellite was used. Vectronic collars used either a Global System for Mobile Communication (GSM) or the Iridium satellite network for data upload and download. For Vectronic GSM collars, a SIM card from a local provider was purchased and sent to the manufacturer and installed in the collar. Followit collars used an international GSM provider. AWT collars <http://www.awt.co.za> utilized asset-tracking hardware re-packaged as a wildlife collar.

GPS positions from Followit collars were listed in a text file, which was received via e-mail. In AWT collars an Excel sheet with the GPS positions was downloaded from the manufacturer's website.

Figure 1. Elephant tracking collar configurations. (A) The two segments of a Telonics collar. (B) Single piece Vectronic collar with directly bolted counter weight at the bottom (AWT and Followit have a similar design). (C) Old Telonics collar belt filled with mud. (D) New Telonics collar slid to the side of the neck of a female.

Old Vectronic collars sent the data via SMS, downloaded to the user's computer through an attached base station. New Vectronic collars offered the options of downloading through a base station as well as receiving a data file via e-mail. Data from Telonics collars was accessed through the Argos website as a downloadable file. Data was kept on the ARGOS server for 10 days only. Vectronic and Telonics data files had to be processed with the manufacturer's software to obtain the actual GPS locations.

Prior to collaring we stencilled a message with a local phone number on the counter weight of each collar, so the finders of fallen collars would be able to contact us. Most collars that dropped off were recovered through this method.

Vectronic, Telonics and Followit collars stored all collected data on-board. If recovered after deployment, the data could be downloaded by connecting the collar to a computer and using a software. Vectronic and Telonics collars required a functional collar battery for direct download but Followit collars could be downloaded even if the battery was dead. For a fee, Vectronic and Telonics collars with dead batteries could be sent to the manufacturer for recovery of data stored onboard. AWT collars did not store data.

Collar cost

Table 2 summarizes collar prices. The prices include shipping to Sri Lanka from the country of manufacture but exclude customs duty (in Sri Lanka, up to 30% of the collar cost). Satellite and GSM providers charged a monthly rental plus a fee for each transmission. The annual cost (Table 2) is based on six GPS locations per day.

Number of tracking days

The average number of data days obtained from all collars was 634.2 ± 355.3 days (Fig. 2A). The longest functioning were two Followit collars (1285 and 1327 days) and the shortest three new Vectronic collars (34, 41 and 45 days).

The four Followit collars functioned for 880.5 ± 516.3 (range 262 - 1327) days. Operational life of the 10 old Telonics collars was 586.8 ± 258.4 (range 307 - 1022) days. The 15 new Telonics collars worked for 855.3 ± 221.7 (range 223 - 1123) days, with 13 collars lasting more than two years. The three old Vectronic collars functioned for 377.7 ± 138.6 days, two lasting less than a year (270, 329 days) and one for 534 days. The eight new Vectronic collars on average lasted 277.6 ± 308.8 days. Seven of them ceased data transmission after less than one year but one collar lasted 976 days. The AWT collar stopped functioning after 428 days (Fig. 2A).

On average collars on 1- (n=3), 4- (n=31), and 8-hourly (n=4) schedules lasted 524.7 ± 390.9, 633.9 ± 362.4 and 862.3 ± 304.9 days respectively.

Number of GPS locations

On average 3333.5 ± 2797.9 GPS locations were received from each collar, ranging from 83 to 15,918 (Fig. 2B).

The four Followit collars provided 4945.3 ± 3306.8 (range 871 - 7651) GPS locations. All were programmed on a 4-hourly schedule.

The 10 old Telonics collars provided 2230.7 ±

Table 2. Cost (US$) of collars (including shipping) and annual data transmission (6 GPS per day).

Collar		Transmission	
Company	Price	Annual cost	Type
Telonics old	NA	950	Satellite (Argos USA)
Telonics new	4920	1200	Satellite (Argos France)
Vectronic old	NA	100	GSM (local)
Vectronic new	3440	100 or 350	GSM (local or Iridium)
Followit	6730	280	GSM (roaming)
AWT	2570	375	Satellite

1249.4 (range 83 - 4601) GPS locations. Nine of them collected GPS every 4 hours. The collar programmed on an 8-hourly schedule gathered 2213 GPS locations. The 15 new Telonics collars collected 3741.1 ± 1316.3 (range 80 - 5280) locations. Twelve of them were programmed on a 4-hourly schedule, two on an 8-hourly schedule and one on both schedules.

The three old Vectronic collars, all programmed on a 4-hourly schedule, collected 1545, 1638 and 2545 GPS locations. The eight new Vectronic collars, four of them collecting a GPS every hour and the others every 4 hours sent on average 3754.3 ± 5323.8 GPS locations. However, three collars sent less than 300 locations. One collar set on an hourly schedule for the first two years and

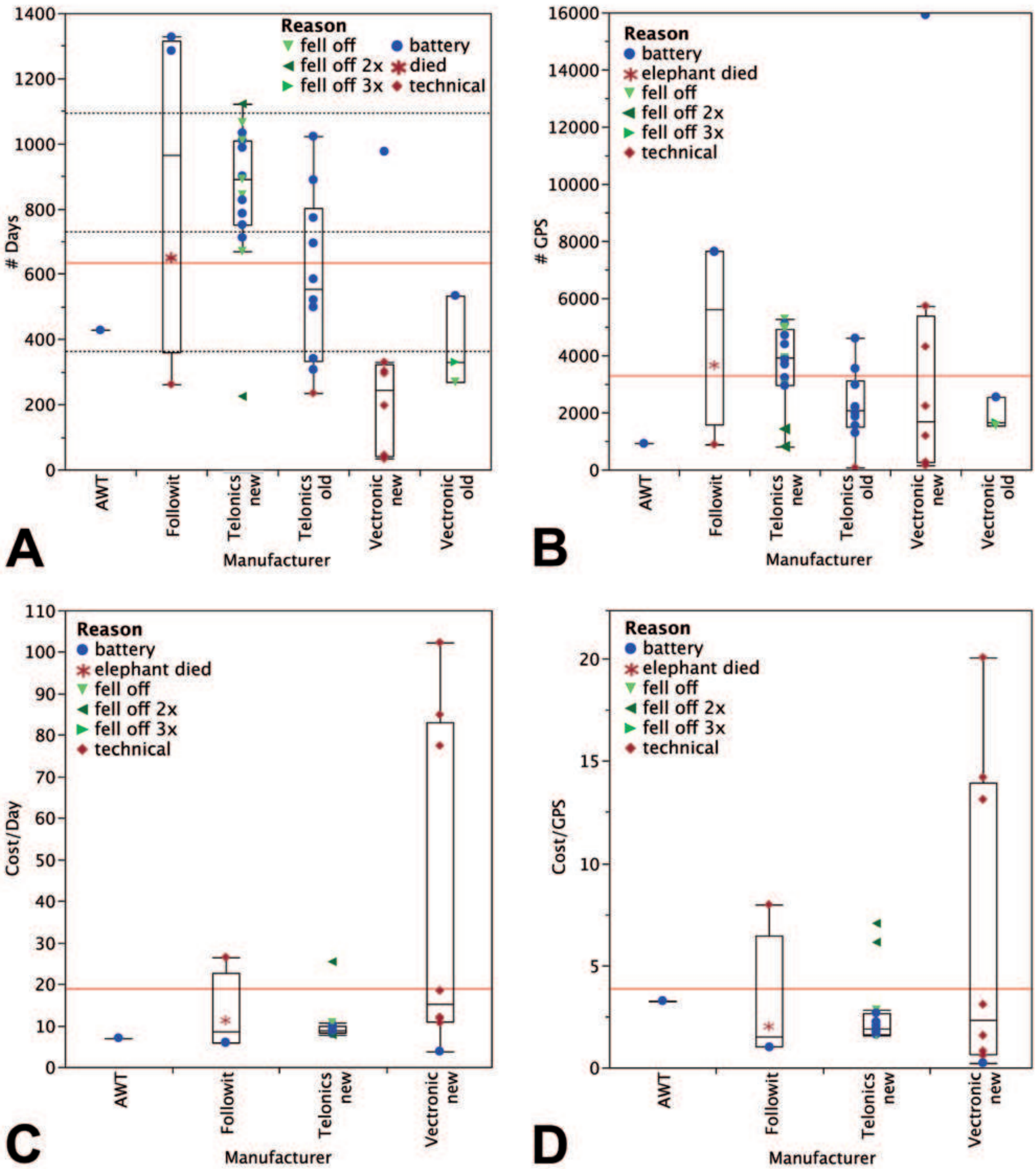

Figure 2. Box plots for the number of tracking days (A) and number of GPS locations received (B) per collar. Average cost in US$ per tracking day (C) and per GPS location (D) based on collar cost and transmission fees. The plotted values are marked according to the reason the collar stopped sending data. The red line is the grand mean. The dashed lines in A indicate full years (1, 2 and 3 years).

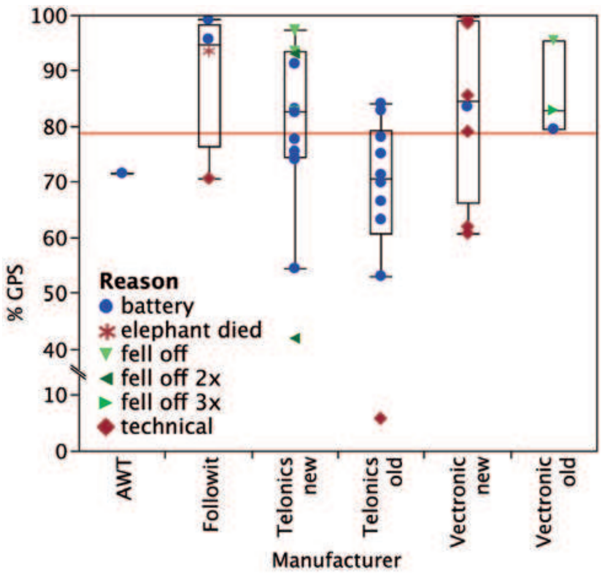

Figure 3. Portion of scheduled GPS received. The red line is the grand mean. The plotted values are marked according to the reason the collar stopped sending data.

thereafter reset to a 4-hourly schedule, provided 15,918 GPS locations.

The AWT collar, which was programmed on an 8-hourly schedule sent a total of 920 GPS locations (Fig. 2B).

Completeness of transmitted GPS data

The 41 collars on average sent 78.2 ± 18.4% of the scheduled GPS positions for the period the collars were active. One old Telonics collar sent only 5.9% of the scheduled GPS positions while one Followit collar provided a 99.7% complete data set (Fig. 3).

The four Followit collars sent on average 89.8 ± 13.0% of the scheduled GPS positions (range 70.5 - 99.2%). The old and new Vectronic collars sent 81.2 ± 2.3% and 83.5 ± 15.8% of the expected GPS locations, respectively. The old and new Telonics collars sent 65.0 ± 22.8% and 81.1 ± 16.0% of scheduled GPS positions, respectively. The AWT collar provided 71.6% of the scheduled GPS locations (Fig. 4). The differences between manufacturers were not statistically significant (Oneway Tukey-Kramer HSD, P=0.15).

Failed GPS acquisition vs. transmission error

GPS locations stored on-board were downloaded from 16 collars recovered after deployment, consisting of 1 old Vectronic, 3 new Vectronic, 1 Follwit, 4 old Telonics and 7 new Telonics collars. These data sets provided all the GPS locations acquired and listed the missing data as failed GPS attempts.

Comparison of the direct download data sets with the data received while deployed showed that the three new Vectronic collars and the Followit collar transmitted all the acquired GPS locations. On average the new Vectronic collars failed to acquire 0.8 ± 0.6% and the Followit collar 6.4% of the scheduled GPS locations (Fig. 4). The one old Vectronic collar did not transmit 3.6% of the acquired GPS locations and failed to acquire 18.3% of the scheduled GPS locations. The old and new Telonics collars failed to transmit on average 4.8% ± 2.3 and 1.5 ± 0.7% of the acquired GPS locations, respectively. The old Telonics collars failed to acquire an average of 21.3 ± 10.9% and the new Telonics collars 12.4 ± 20.2% of the scheduled GPS positions.

Overall the 16 investigated collars lost 12.5 ± 15.5% (range 0.3 - 57.0%) of scheduled data points due to failure to acquire a GPS position and 2.1 ± 2.2%, (range 0 - 8.2%) from inability to transmit an acquired position.

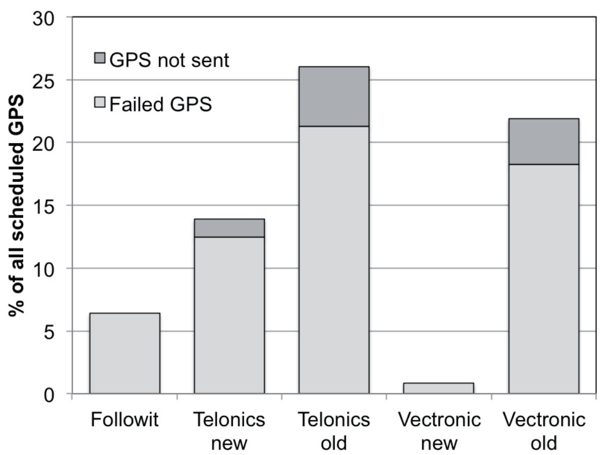

Figure 4. Portion of scheduled GPS not taken and successfully acquired GPS not transmitted.

Cost per tracking day

The average cost per tracking day for all collars was US$ 18.83 ± 25.20 (range 3.80 -102.14, Fig. 2C), excluding the old Vectronic and old Telonics collars (prices unknown).

On average a tracking day with Followit collars cost US$ 12.36 ± 9.71 (range 5.84 - 26.45) and with new Telonics collars US$ 9.98 ± 4.34 (range 7.67 - 25.35). New Vectronic collars cost an average of US$ 40.12 ± 40.53 per day, including the cheapest (US$ 3.80) and most expensive collar (US$ 102.14) in the data set. The AWT collar provided data for US$ 7.03 a day (Fig. 2C).

Cost per GPS location

The average cost per GPS position for all collars (excluding old Telonics and old Vectronic collars) was US$ 3.84 ± 4.69 (range 0.23 - 20.07, Fig. 2D).

Followit collars provided a GPS location at US$ 2.99 ± 3.34 (range 1.01 - 7.96) and new Telonics at US$ 2.57 ± 1.68 (range 1.57 - 7.06). Each location received from new Vectronic collars cost on average US$ 6.71 ± 7.83 (range 0.23 - 20.07) and from the AWT collar US$ 3.27 (Fig. 2D).

Reasons for failure

In one of the 51 collar deployments the collar dropped off before the battery expired, due to belt failure (Fig. 2). Ten collars (34%) were affected, with two coming off the elephant twice and one three times. Belt failure occurred in Telonics and Vectronic collars. The old Vectronic collars (2 collars, 4 elephants) came off within a year (8, 44, 99, 270 days). In three instances, the Telonics collars lasted for less than half a year (28, 35, 117 days) and seven collars came off between 668 - 1065 days.

Seven of the eight new Vectronic collars ceased functioning after less than a year (177.9 ± 135.5 days, range 34 - 331 days). The failure was caused by damage to the casing of the functional unit and consequent electronic failure, possibly due to moisture/water damage.

An old Telonics and a Followit collar stopped functioning prematurely due to electronic failure, without obvious damage to the casing (Fig. 2). The old Telonics collar sent very little data and the battery drained early (236 days). It is unclear if the GPS or the transmitter or both were at fault. The Followit collar failed after 262 days. It had an electronic malfunction, which caused the battery to drain quickly.

Presumed battery life differed between collar models and individual collars (Fig. 2, Table 3). Old Telonics collars lasted between 307 to 1022 days. The batteries of the old Vectronic and AWT collars lasted more than one year. With one exception (712 days) the new Telonics collars had a battery life of more than two years. Batteries on Followit collars lasted more than three years.

Discussion

Collar configuration

In all collars, location of the entire functional unit on top resulted in a high profile that projected above the elephant, causing increased damage from striking objects, especially where elephants frequented thick and thorny scrub habitats. Location of the functional unit at the bottom as in VHF-only collars would be preferable as it is then well protected from such abuse. In an age of ubiquitous inter-device wireless communication it is surprising that all available elephant GPS collars employed a counterweight, which more than doubled the weight of the collar.

Of the two collar designs evaluated, fixing the counter weight directly onto the belt was easier in the field, than bolting together the long and

Table 3. Usage time (days) of collars that reached the end of battery life.

Manufacturer	N	Mean	Stdev	Min	Max
Telonics old	8	617	256.0	307	1022
Telonics new	8	876	124.7	712	1033
Vectronic old	1	534		534	534
Vectronic new	1	976		976	976
Followit	2	1306	29.7	1285	1327
AWT	1	428		428	428

short segments of belting as in the Telonics collars. The latter required bolting at two widely separated points, which were sometimes not easily accessible when the elephant fell on scrubby or thorny vegetation.

Adjustability of collar size is a must and collars should have perforations that allow adjustment between the smallest and largest elephant that maybe collared. Most manufacturers will comply and provided factory perforated collars to cover the specified sizes. Collar size should be re-checked prior to collaring and the perforations tested to see that the bolts fit through them easily.

The use of 13 mm nuts and bolts for collar fixing is preferable to 10 mm, as under the stress of collaring where expediency is key, the larger size makes for easier manipulation and dropped and lost nuts less likely.

Belting

Belt durability is a tricky issue as ideally the belts should last the functional life of the collar and break off subsequently. This maximizes data acquisition and obviates the need to anaesthetize the animal to remove the collar. While removing dysfunctional collars is desirable from an animal welfare point of view (Casper 2009; Ferreira *et al*. 2013), anaesthetizing a wild elephant poses a risk to the life of the elephant and those undertaking the operation. Also, the current cost of anaesthetizing a wild elephant in Sri Lanka is around US$ 2000. Therefore, collars are not taken off as a rule in Sri Lanka. Collars dropped off due to degradation of the collar material and wear and tear, usually within five years.

Premature belt failure was an issue with some collars such as the old Vectronics. However, belt life was determined by a number of variables. Failure due to wear and tear was much greater in thorny scrub habitats and with males. It is also likely to vary with individual elephants. Overall, multilayered canvas belting as used by Followit appeared to be the best with most lasting the life of the batteries and dropping off soon after. The Followit belting material did not degrade and only got abraded, but tore between fixed and flexible points as at the junction of the functional unit or counter weight and the belt.

In general, collars with stiffer belting were liable to fall off unless fitted close to the neck size. Collars with flexible belting tended to be more forgiving of loose fitting as the belt conforms to the neck shape and is prevented from dropping off by the head and ears. Stiffer belting is also liable to cause the functional unit to slide off the top to a side, especially on females, as their neck is narrower and more pointed dorsally. All tested collars had a flat underside to the functional unit meant to be on top of the neck. Shaping the underside of the functional unit to provide a better fit would be an easy improvement.

Collar switch-off

In Sri Lanka elephant immobilization for collaring is the exclusive preserve of the Department of Wildlife Conservation. Due to various administrative and logistic issues sometimes it took over a year after receiving the collars, for them to be deployed. Sometimes a collaring was scheduled and cancelled at the last minute, and rescheduled for months later. Therefore the inability of AWT collars to be switched on/off by the user was a major disadvantage. This may not be an issue where operations can be planned reliably.

Telonics and Televilt collars provided an assessment of collar function when activating them, through LED or VHF signals. However given the logistics and risks of collaring an elephant, we found it prudent to switch collars on a few days prior to deployment and ensure that data was received without any issues.

VHF

All collars had a VHF unit in addition to the GPS unit. The VHF unit was usually powered from a supplementary pack, so that it could be used to locate the collar once the GPS batteries were exhausted. This feature would also be of value if collars are to be taken off after cessation of GPS transmission. We found the VHF helpful to locate and recover collars that fell off and were unable to acquire GPS signal from where they lay. The VHF was also useful for tracking elephants in real time through homing-in, as often the GPS data was from many hours earlier.

Real time communication with the collar GPS through a hand-held unit and a 'go to' facility as found in some hand-held recreational GPS units such as the GARMIN Rino (http://sites.garmin.com/en-US/rino), would provide much better tracking than possible with VHF, especially when combined with a screen map showing the collar and observer position.

Data download

If collars are deployed in areas with good mobile phone coverage, a local GSM provider is the cheapest option for data download. Addition of a data-roaming facility increases probability of data download where coverage is patchy and from different providers. Satellite phone systems such as Iridium and Inmarsat should have greater coverage and be more suitable for areas without local GSM coverage. Satellite phone charges were comparable to cost of GSM plus roaming.

Argos satellite collars had an advantage in ensuring data transmission, as they had global coverage. However, rapidly increasing global satellite phone coverage is likely to obviate this advantage. Argos-based data transmission was much more expensive. While providing exactly the same Argos service, CLS America was cheaper than CLS France. As expected collar life is three years, maintaining payments of high download fees may be a constraint. Using ARGOS imposed limitations on timing of data upload from a particular location. As most Asian elephants remain under cover during the day and venture into open areas during the night, data transmission at dusk or dawn is likely the best.

Failed positions

Overall, collars failed to provide close to one fourth of scheduled positions. The different collar types showed variable extents of failure. The new Vectronic and Followit collars provided near complete data sets while old Vectronic and old and new Telonics collars had a high percentage of failed positions. Loss of scheduled positions could have a significant effect depending on the cause and extent of loss and type of study.

Failure to acquire GPS positions was more common than transmission failure of acquired positions. The new and old Telonics collars had both issues while new Vectronic and Followit collars were able to transmit all acquired positions.

Studies monitoring impact of management actions on elephants are unlikely to be greatly affected by failure to acquire some positions. Analyses of home range extent and movement patterns are more likely to be influenced by systematic bias in GPS acquisition failure. Similarly habitat use and preference studies may be greatly impacted, especially as GPS acquisition failure is likely to be related to variables such as high canopy cover, hence introduce significant bias. Transmission failure may introduce bias due to area of coverage in SMS download and habitat correlates in the case of Argos.

Downloading data stored on-board

Downloading data stored on-board is useful for assessing the relative importance of transmission and GPS acquisition failure. In cases of transmission failure, it provides a more complete data set. The ability to download data with a dead collar battery as in Followit collars is desirable as in many cases collars dropped off and were recovered long after the batteries had expired.

Data processing

Data processing was easiest with the Followit collars as the e-mailed text file listed the GPS locations. The old Telonics collars required considerable data processing effort as downloaded files had to be processed to get the GPS locations and then the locations received had to be sorted in a time-consuming process to remove duplicates and errors. For both old and new Telonics collars, since the Argos server kept the data only for 10 days, the data had to be downloaded regularly without fail throughout the life of the collar. Data processing effort and capacity may be an issue in monitoring programs run by wildlife managers especially in developing countries and maybe a factor in collar selection.

Collars by manufacturer

Followit collars – The Followit collars performed very well, lasting long on the elephant and sending most of the scheduled GPS locations. The three well-functioning Followit collars provided the most complete data sets (>93%). The two collars reaching the end of battery life provided the most tracking days (1285, 1327) and sent the most GPS locations (7623, 7651). They also turned out to be the second cheapest option when considering the cost per GPS location (US$ 1.01, 1.02). One elephant died 648 days after collaring and the collar was not reused. The fourth collar had a technical failure, which caused the battery to drain quickly. The company accepted the fault and offered to refurbish one collar for free, so our financial loss was limited to the cost of collaring.

Telonics collars – Overall, the Telonics collars were very reliable. They provided the third highest number of tracking days and performed well in terms of the number of GPS and completeness of the data set. The new Telonics collars functioned better than the old ones. The cost per tracking day (US$ 9.98 ± 4.34) or per GPS (US$ 2.57 ± 1.68) was less than for Followit or new Vectronic collars. While 10 Telonics collars came off the elephant before the batteries were empty, only three did so in less than a year. One old Telonics collar had an unknown technical problem, which only let it transmit 83 GPS locations in 236 days. The main advantage of the Telonics collars is the Argos transmission, which is global in extent. This is an important consideration when studying elephants roaming over areas with no GSM coverage. While the Argos fees are very high, as the collars generally sent data for a longer period, the actual cost per tracking day and the cost per GPS was about the same as with an AWT collar.

AWT collar – The AWT collar did fine with the number of tracking days (428), which corresponded to what they are advertised for. However, the number of GPS locations (920) and especially the completeness of the data set (71.6%) were not so impressive. The cost per tracking day was US$ 7.03, which was in the same range as Followit and Telonics collars. However, the cost per transmitted GPS (US$ 3.27) was higher. For short-term studies or those with a low budget, AWT collars are a good option.

Vectronic collars – The old Vectronic collars had an issue with belt failure. Seven of the eight new Vectronic collars stopped functioning due to the elephants damaging the case with the electronics. We received a first set of four collars which all stopped sending data within weeks (35, 41, 45 days) or months (196 days). The company replaced the collars and three of the new batch stopped functioning after about 300 days due to damage to the functional unit. Because of these problems the number of tracking days and number of GPS received was low. Less days and less GPS also means that the prices were higher compared to other companies. The failure of the Vectronic collars have to be viewed in the context that all of them were deployed on adult males that ranged outside protected areas. Such animals are more likely to traverse thick thorny scrub, as they hide inside patches of vegetation during day and come into open areas in the night. One of the new Vectronic collars worked perfectly. In 2.7 years the collar provided 15,918 GPS locations. The completeness of the GPS data set (83.6%) was also very good. The cost per GPS for this collar was the cheapest at only 23 cents. If Vectronic sorts out the problem with the belting and encasing of the electronics, their collars would be a very good option. It is particularly useful that a local SIM card can be used, which makes for very cheap data download.

Conclusions

None of the collar models tested worked consistently and individual variation in collar performance was high. This may be partly due to variations in field conditions, but also to variation in assembly. Because collaring an elephant is a major operation, is costly, and presents risks to the elephant and collaring team, it is very desirable that the collars last long. Duration of collar life is particularly important in evaluating seasonal movements and inter-annual variation in ranging which requires multi-year data. Monitoring management actions such as elephant drives and translocations may not necessarily require long-term data. However, even in such cases, evaluation of long-term impacts on elephants is critical from a conservation point of view.

For most studies and especially for detailed analysis of elephant movements and habitat use, a data set without gaps is very important. Therefore, data download options and suitability to area where the collars will be deployed are important considerations. If the collars last longer and send more data, the cost per day and per GPS decrease. Therefore, it is well worth to pay more for a collar with a longer life. However, if then the collar has a technical problem, the financial loss is greater. Given that none of the collars were entirely reliable, whether to hedge the bets with shorter lasting less expensive collars or gamble on more expensive, potentially longer lasting collars, has to be considered.

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References

Alfred R, Ahmad AH, Payne J, Williams C, Ambu LN, How PM & Goossens B (2012) Home range and ranging behaviour of Bornean elephant (*Elephas maximus borneensis*) females. *PLoS ONE* **7:** e31400.

Baskaran N, Varma S, Sar CK & Sukumar R (2011) Current status of Asian elephants in India. *Gajah* **35:** 47-54.

Campos-Arceiz A, Larrinaga AR, Weerasinghe UR, Pastorini J, Leimgruber P, Fernando P & Santamaría L (2008) Behavior rather than diet mediates seasonal differences in seed dispersal by Asian elephants. *Ecology* **89:** 2684-2691.

Casper RM (2009) Guidelines for the instrumentation of wild birds and mammals. *Animal Behaviour* **78:** 1477-1483.

Fernando P, Wikramanayake ED, Janaka HK, Jayasinghe LKA, Gunawardena M, Kotagama SW, Weerakoon D & Pastorini J (2008) Ranging behavior of the Asian elephant in Sri Lanka. *Mammalian Biology* **73:** 2-13.

Fernando P, Janaka HK, Prasad T & Pastorini J (2010) Identifying elephant movement patterns by direct observation. *Gajah* **33:** 41-46.

Fernando P & Pastorini J (2011) Range-wide status of Asian elephants. *Gajah* **35:** 15-20.

Fernando P, Leimgruber P, Prasad T & Pastorini J (2012) Problem-elephant translocation: Translocating the problem and the elephant? *PLoS ONE* **7:** e50917.

Ferreira GA, Pinto ML, Nakano-Oliveira E & Genaro G (2013) Dermatitis prompted by a collar employed in radio-telemetry monitoring. *Animal Welfare* **22:** 195-197.

Pastorini J, Janaka HK, Nishantha HG, Prasad T, Leimgruber P & Fernando P (2013) A preliminary study on the impact of changing shifting cultivation practices on dry season forage for Asian elephants in Sri Lanka. *Tropical Conservation Science* **6:** 770-780.

Pinter-Wollman N (2009) Spatial behaviour of translocated African elephants (*Loxodonta africana*) in a novel environment: Using behaviour to inform conservation actions. *Behaviour* **146:** 1171-1192.

Saaban S, Othman NB, Yasak MNB, Nor BM, Zafir A & Campos-Arceiz A (2011) Current status of Asian elephants in Peninsular Malaysia. *Gajah* **35:** 67-75.